PROCESSING PROCEDURES: DRIED MEATS

Introduction

Dried meats can be classified as dry and semi-dry sausages, dried (i.e., dry cured) whole muscle meats, and whole muscle meat snacks. Dry and semi-dry sausages are probably the largest group and includes pepperoni, Genoa salami, hard salami, Italian salami, dried meat sticks, as well as summer sausage, thuringer, Lebanon bologna, etc. Shelf-stable semi-dry sausages must have a moisture protein ratio of 3.1:1 or less and a pH of 5.0 or less, according to FSIS labeling standards. Dried (mostly dry cured) whole muscle products include prosciutto, parma and country hams as well as pancetta, cappocola, coppa, bresaola, etc. “Whole muscle” meat snacks are mostly beef jerky products (which are usually made from strips of whole muscle), but also include size and form variations such as “steak bites,” “beef bites,” “beef nuggets,” etc.

This section will describe typical processing methods for shelf-stable meat and poultry products to allow you to recognize the processing procedures and equipment within an establishment. You will see that many of the procedures are very similar to those utilized in the production of not-shelf-stable meat and poultry products.

This section will cover:

1. Composition of meat and factors affecting moisture removal, color, and oxidation (rancidity).
2. Typical processing methods and equipment for the production of fermented, acidified, and non-acidified dry and semi-dry sausages.
3. The production steps for dry whole muscle products.
4. The production steps for dry whole muscle meat snacks.
5. Parameters important to the production of the specific dried shelf-stable product types.

At the end you will be able to:

1. Recognize the relationship between meat chemistry and moisture removal for dried meat products.
2. Describe the production flow and pertinent equipment for the production of dry, dry-cured, or fermented /acidified shelf-stable products from batching to labeling.
3. Associate different processing methods/equipment with their corresponding critical parameters.

Chemistry of Shelf-Stable Meat Products

To understand some of the meat processing procedures and principles, you must first understand the composition of meat and how this and meat additives affect the water holding capacity, color and deterioration properties of meat and meat products.

►Composition

The three major components of meat (muscle) are water, protein and fat. Lesser components are carbohydrates and ash (minerals).

Water

Water is by far the largest component of meat, comprising 65-80% of the lean tissue. The water present in muscle functions as a solvent for the transportation of metabolites and as a medium in which reactions occur. In meat, water provides juiciness, color, and also acts as a solute.

Generally, the water content of meat is about 3.5 to 3.7 times the amount of protein. Fat tissue commonly contains 5-8% water; thus, meat with higher fat content will have less protein and water. Water plays a significant role in processed meats because additional water is added to emulsion-type products and to cured whole muscle meats through the use of curing brines. Obviously, water loss lowers processing yield, which generally is not desirable in cooked meats but is desired in fermented and other dried meats. The manipulation of water content in processed meat is critical to the successful production of the entire range of processed meats.

Water exists in meat as

1. bound (restricted or immobilized) water, and
2. free or bulk water.

One type of bound water, often called restricted or immobilized water, is attracted to the protein, forming loosely ordered associations. For example, when salt is added to meat, it increases the amount of restricted water due to its effect on the meat proteins; thus, “binding” of the water occurs. Another type of bound water is the water structurally associated with meat proteins, membranes and connective tissue. This bound water can only be removed by very high heat such as when meat is ashed (3-5% of total water). Bound water is not available for microbial activities.

Free or bulk water in meat is held only by weak forces such as capillary action. Ground beef will hold more free water than a steak due to the greater surface area. The measurement of water activity expresses the amount of "free water" in the meat. Free water is readily available to microorganisms for growth.

Protein

The function of proteins in meat is for nutrition, texture, color, and water holding capacity. Protein can be categorized into three types.

1. Myofibrillar (contractile) proteins – salt soluble,
2. Sarcoplasmic (plasma) proteins – water soluble,
3. Stromal (connective) proteins – relatively insoluble.

The myofibrillar (or contractile) proteins, form the largest structure and bulk of muscle. These proteins (e.g., actin and myosin) form the structure called myofibrils inside the muscle cell and are responsible for the contraction ability of living muscle. The most expensive raw meat materials generally contain the highest level of this protein group. The myofibrillar proteins are distinguished from the other meat proteins because they are soluble in high salt solutions and thus, are often called the "salt soluble proteins." These proteins are insoluble in normal meat, but they will absorb enough water in the presence of salt (i.e., high ion concentration) that they become soluble. This ability to become solubilized makes the myofibrillar proteins very valuable in processed meats by allowing them to retain water and encapsulate fats, thus preventing separation during cooking.

The plasma (or sarcoplasmic) proteins are found inside the muscle cell. They are part of the fluid mass that bathes the myofibrillar proteins and provides the necessary biochemical functions to provide energy, to synthesize protein and to remove metabolic by-products. The plasma proteins are already soluble in the muscle cell, hence are called water soluble proteins. This group of proteins is most identified by observing the fluid that drips from thawed meat. There are hundreds of different plasma proteins found in small quantities in meat. Myoglobin is the one plasma protein that has significant importance in processed meats because myoglobin gives meat its color. The heme (iron) portion of myoglobin has an active site that binds various compounds. The compounds (e.g., oxygen, nitric oxide) bound to the myoglobin gives different colors to meat.

The connective tissue (or stromal) proteins transmit the movement generated by contraction of the myofibrillar proteins to the skeleton of the body. This function requires connective tissue to be very tough and strong. Collagen is the major connective tissue protein in meat. It is similar to the collagen found in skin, ligaments and tendons. Collagen content varies among different muscles and even within the same muscle. Muscles used for locomotion, such as leg muscles, have higher collagen levels than muscles used for support such as the loin. Where muscle attaches to bones, collagen levels increase in concentration. Older animals do not necessarily have greater amounts of collagen, but they do have tougher collagen. For these reasons, meat from leg muscles from older animals is too tough to be eaten as steaks, chops, or roasts. The high collagen and tough collagen meats are diverted to sausage products where collagen is reduced in size by grinders, cutters, choppers or mills. Collagen in sausage products is not highly desirable. Collagen is a structural protein, but unlike the myofibrillar proteins does not solubilize in a strong salt solution. Upon heating, collagen will soften and turn fluid-like. These properties are undesirable for forming emulsions. For this reason, high collagen meat materials, such as jowls, cheek meat and navels have low bind values. Collagen is also unique because it hardens when dried, which is an important characteristic for sausage casings. Casings made of natural and reconstituted collagen are excellent because the collagen becomes a strong package when it dries.

Fat

Fat (lipid) is the most variable component in meat. It functions for flavor, texture, and juiciness. It also impacts shelf-life and profits. Fat cells are almost completely filled with lipid. Animal lipids are generally triglycerides, which are glycerol molecules with fatty acids attached.

There are many different fatty acids. They differ in the number of carbon atoms in the carbon chain, ranging from 12 to 20, and the number of unsaturated double bonds. A single bond between carbons is called a saturated bond and a double bond is called an unsaturated bond. The combination of different carbon length fatty acids and different amounts of unsaturated bonds give fatty acids varying properties, giving fat its unique characteristics. The fat melting point is one measure of the effect of varying chain length and unsaturation. With decreased chain length and increased unsaturation, melting point in lowered. Unsaturated bonds have the greatest influence on melting point because they are more susceptible to breakage by heat than are saturated bonds. This greater susceptibility of double bonds is important in processed meats during the emulsion formation and in shelf-life.

During chopping and emulsifying, the temperature of the meat batter is generally brought to 60°F to 65°F (15.6°C to 18.3°C) by mechanical energy. Pork fat has more unsaturated fatty acids than beef, so it has a lower melting point. During the emulsification process, a product that has predominantly beef fat should be chopped to 63°F to 65°F (17.2°C to 18.3°C).

In dried meat products, it is not desirable to melt the fats at the initial stages of the production process because this would retard moisture loss. Thus the meats are formulated very cold. Pepperoni is typically formulated at about 33% fat with an ultimate target of 42% fat and 1.6:1.0 moisture to protein ratio, after a 33%

shrink. During the fermentation and cooking process, the formulated chemistry changes, with decreases in moisture and weight accompanied by increases in percent fat and protein. This is also typical of other dried meat products.

Other compounds

Other compounds in meat include carbohydrates, minerals and vitamins. These compounds comprise about 1% of the meat and have little influence on the meat properties. In dried meats, particularly fermented products, carbohydrates in the meat are not sufficient for adequate fermentation, although some minimal activity will occur depending upon the residual glycogen. Added sugars serve as substrates for microbial fermentation/activities, and it is essential to control the carbohydrate type and amount. In general, dextrose is the preferred added carbohydrate; the final pH is directly dependent on the amount added and the initial pH of the meat mix.

►Water Holding Capacity (WHC)

Water holding capacity is one of the most important meat properties. In manufacturing processed meats (e.g., bologna or other emulsified products), different techniques are used to raise WHC such as adding salt and phosphates, chopping and emulsifying. Increasing WHC is basically altering the myofibrillar proteins so that they will bind more water. If the myofibrillar proteins bind enough water, they become soluble in water, and, thus, do not separate or settle out of the water. Solubilizing some of the myofibrillar proteins is essential to forming an emulsion, or matrix, and encapsulating the fat (also binding meat pieces).

In meat tissue, the water holding capacity (WHC) of the meat proteins generally is favored at higher pH. In dried meats, we want to lower the WHC of meat in order to efficiently remove water and thus lower moisture content and water activity. In dried meats, moisture loss is the objective, thus fermenting or acidifying the product provides for efficient loss of moisture as the proteins contract and expel water. As the pH is lowered, meat proteins release water with the subsequent drying of the product.

In non-acidified dried meats, it is more difficult to remove the water due to the higher pH. This is perfectly illustrated when comparing fermented to non-fermented meat snacks. The fermented products show a relatively smooth surface due to the efficient drying at the lower pH, while the non-fermented products show a rough surface due to non-uniform drying at the higher pH.

►Meat Color

Meat color is dependent on myoglobin protein, which is part of the sarcoplasmic, or plasma, proteins (water soluble proteins). Within the myoglobin protein structure, there exists a heme structure that normally contains iron (Fe). The oxidation state of this Fe, the protein structure (soluble or denatured), and the total amount of myoglobin in the meat determine its color. The amount of myoglobin will vary depending on species (beef>pork>poultry), age (mature>young) and muscle type.

Fresh meat, in the presence of oxygen appears bright red; in the absence of oxygen, it appears purple-red. In cured meat, nitric oxide (from added nitrite) replaces the oxygen molecule in the heme (iron) structure resulting in nitrosomyoglobin, a deep red pigment color. As the meat mix is then heated, the protein structure is denatured, resulting in nitrosohemochrome, the typical pink color of many cured meat products. If the product is not heated, the darker red color remains and is stabilized by drying. This is partly the reason many traditional dried meats that are not heated (prosciutto, dry salami) demonstrate a darker red color than cooked and dried products.

►Chemical Deterioration of Dried Meats

Chemical deterioration in dried meats most often refers to lipid or fat oxidation. Oxidation is usually started by the action of a catalyst, which include heat, light, or oxygen. Many different compounds form during oxidation, imparting an atypical flavor and odor in meat known as rancidity. The oxidation of fatty acids develops spontaneously. This chemical reaction is slowed at low temperatures but is not stopped. Meat stored in a freezer will turn rancid more slowly than meat stored in a cooler. Rancid meat is often associated more with frozen meat than chilled meat because bacteria can spoil meat in a cooler before rancidity develops. Rancidity can develop in fermented products rapidly if fermentation bacteria do not produce acid fast enough. This is one reason lactic acid starter cultures are recommended for fermented products rather than relying on viable bacteria occurring naturally or being added from previously fermented products.

To prolong shelf-life and slow fatty acid oxidation, antioxidants (ie.g., BHA, BHT, TBHQ, rosemary extracts) are commonly used. Smoke components can have an antioxidant effect. Antioxidants are not used in some processed meats that contain nitrite, since nitrite is a potent antioxidant. Vacuum packaging of meats removes oxygen, reducing rancidity. Cured items have a longer shelf-life than non-cured items due the antioxidant effect of the nitrite (e.g., ham versus pork roast). Rancidity is a quality issue, not a safety issue.

Workshop: Chemistry of Shelf-Stable Meat Products

The following questions are multiple-choice and True/False questions. Circle the answer(s) you believe to be correct; some questions have more than one correct answer.

1. The three major components of muscle and meat are

   a. water, protein and fat.
   b. carbohydrates, ash (minerals) and protein.
   c. protein, fat, and minerals.
   d. carbohydrate, water, and protein.

2. Water exists in meat in several states. Which state is readily available for microbial growth?

   a. bound water
   b. restricted or immobilized water
   c. free or bulk water

3. Fat melting point is affected by chain length of fatty acids and degree of saturation of carbon bonds.

   a. True
   b. False

4. Final ____________is directly dependent on the added amount of carbohydrate (dextrose) and the initial pH of the meat mix for fermented products.

   a. water holding capacity
   b. pH
   c. water activity
   d. protein content

5. The oxidation state of iron, the protein structure, and the total amount of myoglobin in the meat determine

   a. meat color.
   b. water holding capacity.
   c. tenderness.
   d. solubility.

6. In cured meat, a deep ____ color is due to nitric oxide (from added nitrite) forming nitrosomyoglobin. As the product is heated, the protein structure is denatured, resulting in a bright ____ color.

   a. brown, red
   b. red, brown
   c. red, pink
   d. purple, red

7. Oxidation from unsaturated fatty acids can be initiated by which catalyst(s)?

   a. heat
   b. light
   c. oxygen

8. Oxidation of fatty acids (rancidity) is ______ at low temperatures.

   a. slowed
   b. increased
   c. stopped
   d. not changed

9. Pork fat has more unsaturated fatty acids than beef fat, which makes it

   a. more susceptible to oxidation.
   b. less susceptible to oxidation.
   c. equal in susceptibility to oxidation.

10. Rancidity is the same as biological spoilage.

   a. True
   b. False

11. Rancidity is a safety issue.

   a. True
   b. False

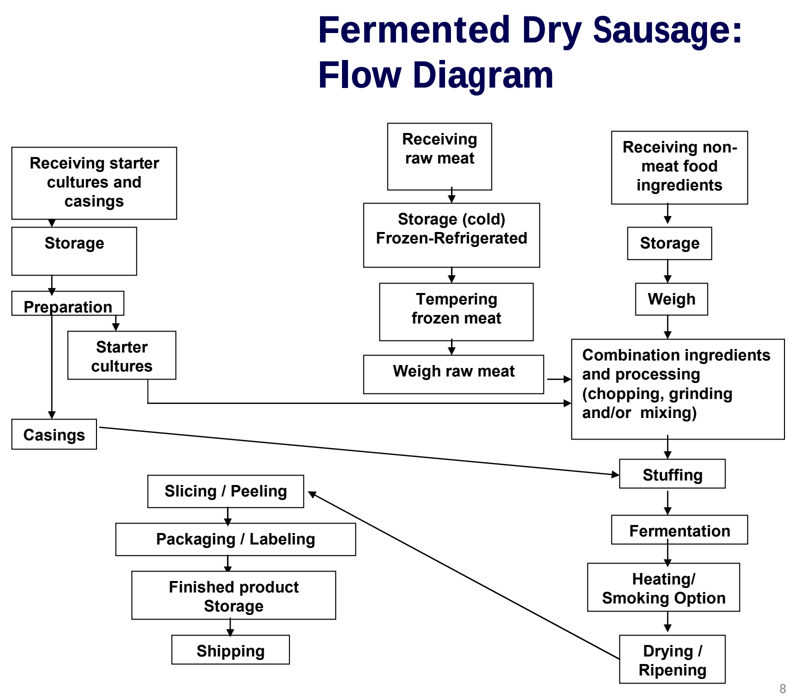
12. Freezing meat stops rancidity.
   a. True
   b. False

Processing Procedures for Dry and Semi-Dry Sausages

Dry and semi-dry sausages are possibly are the largest category of dried meats, particularly in the United States. These products can be further categorized as fermented, acidified with chemical acidulants, or non-acidified. They are, with a few exceptions, generally cooked.

►Fermented Dry Sausage

Fermented dry sausage basically is manufactured by tempering and breaking the raw meat materials; formulating the meat with added cure, starter culture, salt and seasoning mixture; stuffing the product into casings, fermenting, heating, smoking (optional), and drying.



The key considerations for manufacturing fermented dry sausage are as follows:

- Sausage will require 30-40% moisture loss.
- Fat smearing over lean tissue should be minimized to enhance moisture loss and product definition.
- Raw meat mix should be approximately 25-28°F (-3.9 to -2.2°C) when combined.
- Meat mix temperature at stuffing should be 25-30°F (-3.9 to -1.1°C).

- Meat visual defects (e.g., blood clots) should be minimized, since they are magnified with drying.

Formulation and Blending

During formulation, it is important to form a “meat matrix” consisting of lean and fat particles bound together by salt soluble meat proteins. Initially, the meat mixture consists of soft particles, but with the addition of salt, the salt soluble proteins dissolve and provide the “binding” material necessary. When the product is stuffed and fermented, the resulting acid denatures the mixture, which results in increased firmness. If further heating occurs after fermentation, the added heat adds to the firmness and initially accelerates the drying process. If not heated above fermentation temperatures, the product proceeds to the drying stage, which increases firmness with the corresponding moisture loss. The acid coagulation is an irreversible process, thus the product needs to be in the final shape desired prior to this denaturation. For dry sausages, this initial matrix formation needs to occur to some limited extent, but excessive matrix formation (excessive protein extraction) leads to fat and protein smearing. If insufficient matrix formation occurs due to premature acidification, lack of salt, too low temperatures and/or insufficient mixing, the resulting product will be “shorted” (insufficient bind, mushy texture).

In dried, fermented sausages the first steps in production are the size reduction of the meat tissue and the preparation of the non-meat ingredients. The raw meat materials often are frozen, so the meat blocks must be tempered to the desired temperature, and then reduced in size by frozen block grinders, hydraflakers and/or chopping in a silent cutter. Fresh meats must also be chilled to lower the temperature prior to size reduction; they are often used in combination with frozen materials (or addition of carbon dioxide) to control meat mix temperature.

Non-meat ingredients such as the cure mix, seasoning mix (with or without salt), and starter culture are either weighed according to the batch size or are provided by the vendor in unit packs corresponding to the batch size. The starter culture is either added directly, if using a dry culture, or diluted in water first to afford good distribution of a frozen culture. The sausage casings are also hydrated to afford flexibility, if provided in flat stock, or are added to the stuffing horn directly if shirred. Often potassium sorbate is added.

The initial size reduction is very coarse to afford uniform mixing or chopping with the other ingredients, but after formulation the product is re-ground to achieve the final fat particle size for visibility. This product definition is also dependent upon the equipment used and meat mix temperature. Sometimes the product is final ground prior to formulating with the other ingredients.

Generally, prior to the addition of non-meat ingredients, the meat blend is analyzed for fat, and possibly moisture and protein content, to allow for adjusting the blend to the desired formulation. The meat mix may contain various meat types at various temperatures to afford the desired characteristics of the final product and to afford the desired temperature of the total mix prior to stuffing.

If a mixer is utilized, a paddle type mixer is preferred due to less smearing of the meat mix. After the meats are formulated, the non-meat ingredients are typically added in the following order: the cure mix, seasoning mix and the starter culture. Minimal mixing time is recommended to uniformly mix the ingredients but not to over work the mix. Vacuum mixing is optimal but not necessary if using a vacuum stuffer. Some smaller processors historically use a silent cutter or chopper for both size reduction and mixing, but this type of equipment is very operator dependent. After mixing, the product is transferred to the stuffing apparatus. Any product transfer should minimize piping and pumping, with a conveyor system preferred, again to minimize “working” the product. After mixing, some processors may final grind the product prior to stuffing, which also allows use of a bone collector device.

Stuffing

The stuffing apparatus is usually a screw type, piston, or chamber device. During the stuffing phase, it is important to maintain cold temperatures and avoid fat and protein smearing. This is accomplished also by minimizing resistance to the meat mix flow; for example, using the largest stuffing horn possible to fit the casing and using flat stock casing instead of shirred casings. Usually, a vacuum stuffer is employed, which removes oxygen, providing for better curing and concentrating the product going into the casing. For most dried fermented sausages, fibrous, collagen or natural casings are utilized.

At this point, the meat mix is in the casing. Excessive fat smearing will breakdown fats, enhance oxidation and retard drying. This is usually visible under the casing. Excessive dissolved protein smear results in meat fiber orientation and is the major cause of “cupping” in pepperoni on a pizza.

Fermentation

After stuffing, the product enters the fermentation phase. Fermentation from the starter culture will occur once the product temperature is elevated. The fermentation rate will depend upon the formulation parameters and the optimum growth temperature of the starter culture. Fermentation can be accomplished in any environment that provides the necessary conditions (e.g., smokehouse, fermentation chamber). A relatively high humidity (85-90%) is preferred to keep the product surface slightly moist, or “tacky,” during fermentation and prior to subsequent drying. This avoids premature and uneven drying at the surface and the humidity enhances the fermentation. It is critically important to monitor the fermentation for the proper conditions and product pH. A critical control point is the predetermined time interval, under designated conditions, for the product to reach the desired pH, prior to subsequent heating and/or drying. Any monitoring of coagulase positive staphylococci should be done on product at the end of the fermentation cycle, since the potential toxins produced may survive further heating that can destroy the responsible microorganisms.

Relative humidity is extremely important to all dried meat processing because of its impact on the quality of the product. Relative humidity expresses the degree of saturation of the air by vapor, expressed as a percentage. Relative humidity describes the relation of the existing vapor pressure at a given temperature to the maximum vapor pressure at that temperature. Air at a given temperature can absorb water (vapor) until its saturation (100%). Although now we have humidity monitoring devices that give a direct readout of relative humidity, historically processors used dry and wet bulb devices. The dry bulb temperature is the direct temperature readout, while wet bulb is a dry bulb surrounded by a wet sock, providing a lower temperature. The difference between the two readings is the relative humidity at that temperature.

(See http://members.nuvox.net/~on.jwclymer/wet.html for a JavaScript routine that calculates the relative humidity given the wet and dry bulb temperatures.)

Heating and Drying

As previously mentioned, after fermentation the product can be heated prior to drying, or go directly into drying. If heated, the product can be heated to a variety of temperatures depending upon specific validation parameters or desired final product characteristics. Intermediate heating (120-140°F, 48.9-60°C) or fully cooking (155-160°F, 68.3-71.1°C) both provide a means of destroying pathogens potentially present in meat to achieve the desired destruction. Applying heat to fermented products is not always desirable due to the resulting flavor and texture changes; so many processors have arrived at intermediate heating schedules (time/temperature) that meet both objectives for destroying potential pathogens while preserving desired product characteristics. U.S. processors now must validate their own process for the specific destruction of the relevant pathogens (trichinae, *Salmonella*, *E. coli* O157:H7, *S. aureus*, *Listeria monocytogenes*), either by use of literature studies, by conducting a challenge study, or by relying on FSIS Appendix A: Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products.

The variables during cooking and drying are cooking time, dry bulb temperature (generated by gas, steam coil, or electric heat), wet bulb temperature (natural humidity/fresh air/exhaust, steam injection, atomized water and/or refrigeration), and air velocity. Obviously, it is very important to maintain uniform conditions during cooking and drying. This is dependent on cooking and drying room design, product loading, product shape and the drying process. In general, uniform and balanced air flow is critical; typical values for fermentation rooms are 4-6 air changes per minute, and less than 2 air changes per minute for drying chambers. The processing oven should initially be balanced by the manufacturer and periodically checked for uniformity. Generally, ovens have a constant airflow for the supply ducts to the return, but also can have an oscillating airflow.

Product loading is also important to achieve uniform airflow. Uneven loading will result in uneven conditions around the product, regardless of the design of the heating and drying rooms.

Product shape will affect uniform heat transfer. Heat is transferred along the shortest dimension, so naturally shaped products like bacon and bone-in hams will inherently have more temperature variation compared to casing products. Product should be monitored for minimum internal temperature at a predetermined “coldest” spot in the product.

The final drying process is influenced by the previous fermentation and heating processes. Adequate carbohydrate source, the chemical environment, processing temperatures and humidity are the influencing factors during fermentation. During heating after fermentation, the product initially shows fast drying, but subsequently can actually dry more slowly if cooked, due to surface drying and “skin” formation. Finished core temperatures also affect final product texture and appearance, going from more of a “raw” taste and firm bite with definite fat and lean differentiation (final core temperature < 90°F, 32.2°C) to a cooked taste, hard bite, and little fat and lean definition with a fully cooked product (final core temperature > 137°F, 58.3°C).

A cooling step may or may not be employed. A hot shower rinses any residual fat from the surface and can tighten casing onto the product. A following cold shower will quickly reduce surface temperature. Meeting the cooling (stabilization) performance standard to control *C. perfringens* is not needed for this cooling step – the pH of the products is too low for growth at this point. The pH is close to the limit for germination and growth by other sporeformers as well – very limited growth could occur at this point and as the water activity drops in the drying step, sporeformers will be fully controlled.

During the drying process in a dry room, it is very important that the rate of moisture migration from the product center to the surface equal the rate of moisture migration from the surface to the atmosphere. This is more difficult with larger diameter products, and most dry sausages exhibit greater moisture loss at the surface. The controlling factors for drying are temperature, relative humidity, air velocity, and air distribution and direction. If product is dried too fast, case hardening occurs. If product is dried too slowly, mold growth can be a problem.

Mold growth is desirable in some products (e.g., Italian salami) for flavor and appearance, but for most processors, mold growth is a problem. In addition to being visibly undesirable, mold growth can increase surface pH, alter flavor and restrict moisture loss. If only sporadic mold growth occurs, it generally is removed at peeling of the casing and slicing.

Smoking

Smoking of the product, whether using either natural smoke or liquid smoke, can produce desirable effects for specific products. Generally, dried meats are characteristically smoked (hard salami) or not smoked (Genoa salami). Smoking provides color (carbonyls + amines + dry heat) and flavor (phenols), as well as antioxidant (phenols) and antimicrobial (phenols + acids) properties to the product. Smoking should not be done while the product surface is still wet due to the resulting dark brown or "muddy" color and potential "streaking" of the color. Generally, smoking is done toward the end of fermentation. Excessive smoke application in the beginning of the fermentation cycle on small diameter product can inhibit the fermentation activity of the starter culture.

Quality versus Safety

In processing dried meats, there are many formulations and processing conditions that can be varied to balance quality and safety. For example, some processors have elected to remove beef from some formulations that contained pork and beef so that *E. coli* O157:H7 is not a consideration. The rate of pH drop and the final pH can affect both the safety and the quality of the final product. In general, a lower pH provides more safety, but the lower pH can adversely impact taste. The degree of heating (none, partial, or fully cooked) is important in safety (more heat provides greater pathogen inactivation) but changes the characteristics of the product. Heat may be needed to obtain appropriate pathogen inactivation. The relative humidity during drying can also impact both product characteristics and safety. Microorganisms have increased heat resistance to dry heat and at lower a_w. A decreased relative humidity may result in pathogens being exposed to a dry heat, which could increase their chance of survival. As noted before, improper air flow can dry the surface too quickly or too slowly, both of which can impact quality of the product.

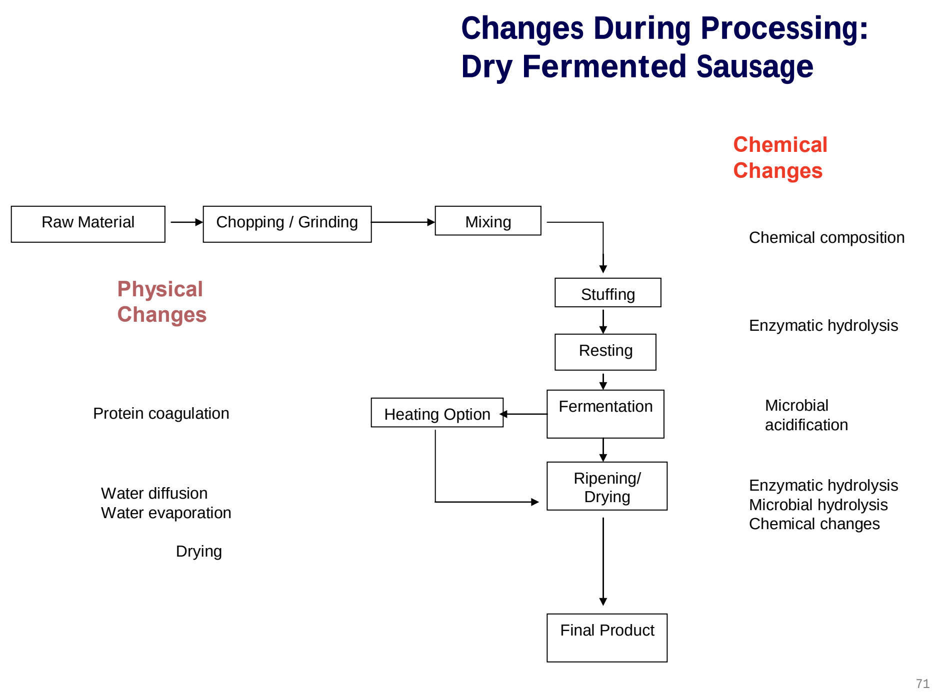
Fermented Dry Sausage: Pepperoni Formulation and Process

A typical example of a fermented dry sausage formulation and process would be that of U.S.-style pepperoni. The product is formulated to about 28-32% fat (figuring 68-70% final yield) considering a least cost formulation, including predominantly pork with some beef. The maximum amount of beef allowed in product labeled as "pepperoni", and not "beef pepperoni" is 55%. Generally, most processors use a minimum 60% pork, but can go to as much as 100% pork depending upon market meat prices and if exported. Pork and beef cheek meat is commonly used (lack of bind, high protein) and is allowed as "meat." Finely textured beef and pork is also allowed and used due to price, but the desired texture and color prevent excessive usage levels.

Non-meat ingredients include:

Salt (bind, flavor, preservative)	2.7-3.5 lb/100 lb meat
Dextrose (limiting, carbohydrate for starter culture fermentation)	0.5-0.8 lb
Spices (mustard for flavor)	0.75-1.5 lb
Natural flavorings (spice extracts for flavor, color)	0.3 lb
Starter culture (*Pediococcus acidilactici* for high temperature fermentation)	0.5 lb diluted
Antioxidant (BHA, BHT, citric acid, rosemary)	in flavorings
Cure (nitrite on salt carrier, color, preservative)	0.25 lb

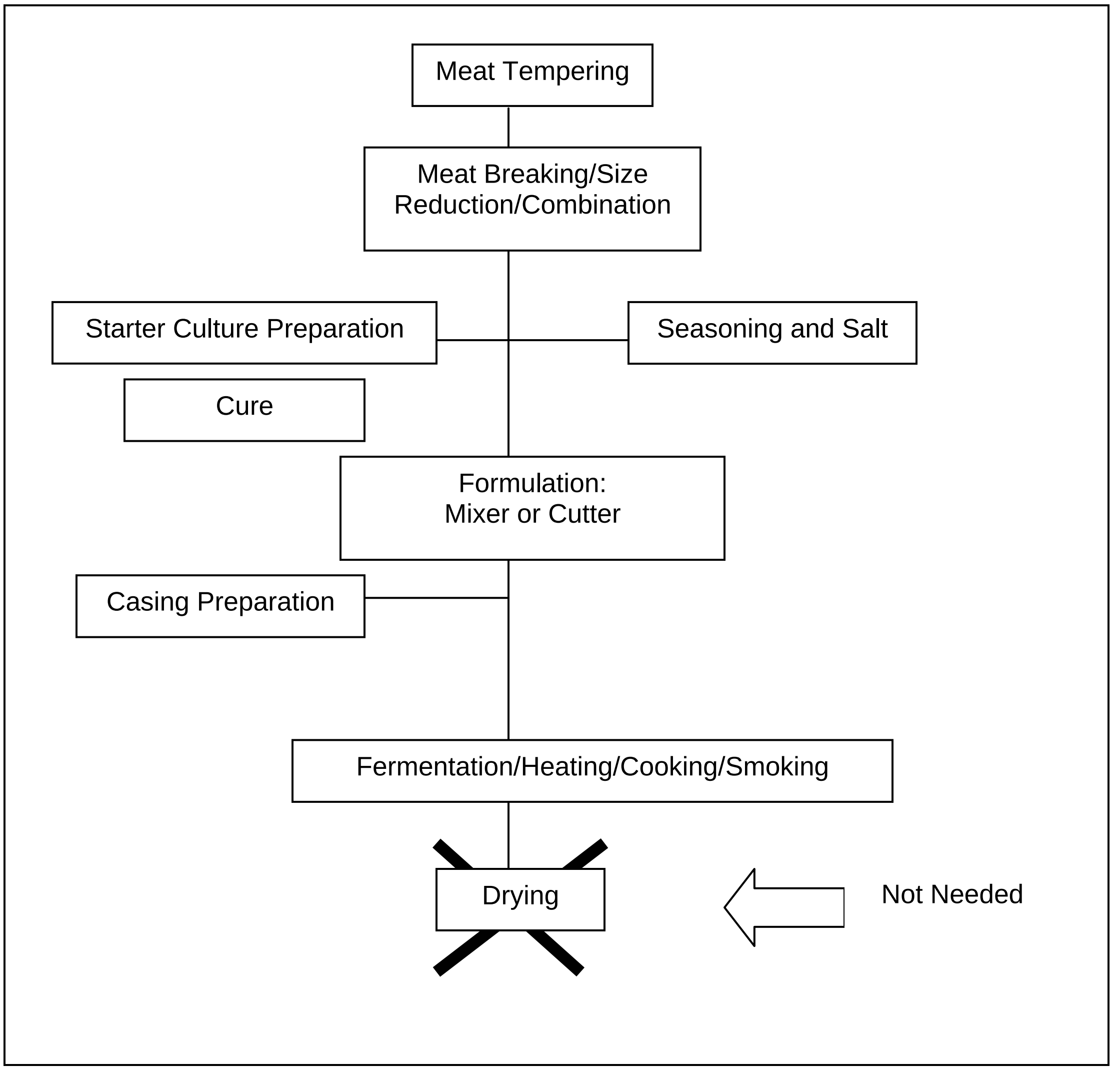
Typically, the meat is tempered to about 26-28°F (-3.3 to -2.2°C) prior to mixing. The entire meat mix is blended with the cure, flavorings/antioxidants, salt and starter culture. After blending and regrinding, the product is stuffed at temperatures not exceeding 26-28°F (-3.3 to -2.2°C). The stuffed product is fermented at 95-110°F (35-43.3°C), 80-90% RH, to pH < 5.0 (typically 8-12 hours), then heated (to a temperature validated for the appropriate pathogens; e.g., 128°F (53.3°C) internal temperature for 1 hour), cooled and dried (50-55°F (10-12.8°C), 68-72% RH) until moisture/protein ratio reaches 1.6 or less (typically 12 – 14 days). The MPR is used mostly for labeling purposes and has limited use in food safety. A more reliable measure for food safety is the a_w.



►Fermented Semi-Dry Sausages

Summer sausage, Lebanon bologna and thuringer are examples of fermented semi-dry sausages. These products are manufactured in much the same way as the fermented dry sausages but with a few distinctions. In general, semi-dry sausages, as the name implies, do not lose as much water (10-15% loss) as dry sausages (30-40% loss). The drying occurs during fermenting and cooking, so a specific dry room is not needed. Fat and protein smearing are not as much of an issue due to less moisture loss, so formulation temperatures are higher, in the range of 28-40°F (-2.2 to 4.4°C). Most semi-dry types are cooked following fermentation and exhibit finer grind and lower pH (<4.8). A typical summer sausage process would include a fermentation period of 12-16 hours at 100°F (37.8°C), 98% RH, to a pH < 5.0, followed by a smoking/cooking cycle to a minimum of 140°F (60°C) internal temperature. Many products are shelf-stable, with limiting amounts of added sugars (to prevent secondary fermentation in the vacuum package) and fully cooked to 160-165°F (71.1-73.9°C) internal temperature.

Fermented Semi-Dry Sausage



►Chemically Acidified Sausages

Some dried meat products are formulated with chemical acidulants, rather than starter cultures, which accelerate the process by eliminating the fermentation period. These chemical acidulants provide a slower release of the specific acid (as opposed to addition of the straight acid) into the meat mix in order not to result in premature acidulation before the meat matrix is established. These types of acidified, product processes are direct heated and cooked following formulation.

Chemical acidulants can be encapsulated acids or the slow release acid glucono-delta-lactone (GDL). With encapsulated acidulants, the active acid ingredient (e.g., lactic, citric, fumaric, GDL/gluconic acid) generally is encapsulated with fat material that melts at varying temperatures, thus releasing the acid. Thus, acidification occurs during the cooking process after the meat matrix has been established. The rate of acid release is dependent upon the specific particle size, fat coating, temperature, other fats in the formulation, physical processing, and processing temperature.

GDL is a cyclic compound that releases gluconic acid slowly when the GDL is hydrated with the meat moisture. When GDL is added to the meat mix, the product must be stuffed and processed immediately, before significant acid formation. The rate of acid generation is dependent upon moisture content and temperature.

A typical process for chemically acidified summer sausage would consist of formulation, followed by heating at 115°F (46.1°C), 74% RH, and then cooking to 165°F (73.9°C) internal temperature. The entire process takes 6-7 hours versus a 12-18 hour fermentation process.

►Non-Acidified Dried Sausages

Some dried sausages are not fermented or acidified. This product segment includes a portion of the dried meat snacks (meat sticks) and some larger diameter sausages, particularly those exported to Japan and other markets where acidity or tang is not a popular flavor. These products have the same general formulation process as fermented dried sausages, but no starter cultures or acidulants are added during formulation and no fermentation period is required. Generally, after stuffing, the products are cooked to 146°F (63.3°C) and then dried to a water activity of < 0.86. Due to the higher pH, these products must be dried to a lower water activity (less moisture) than fermented products to achieve shelf-stablity. The higher pH makes the product more difficult to dry and tight control of temperature, humidity and airflow is critical.

Dried Whole Muscle Products

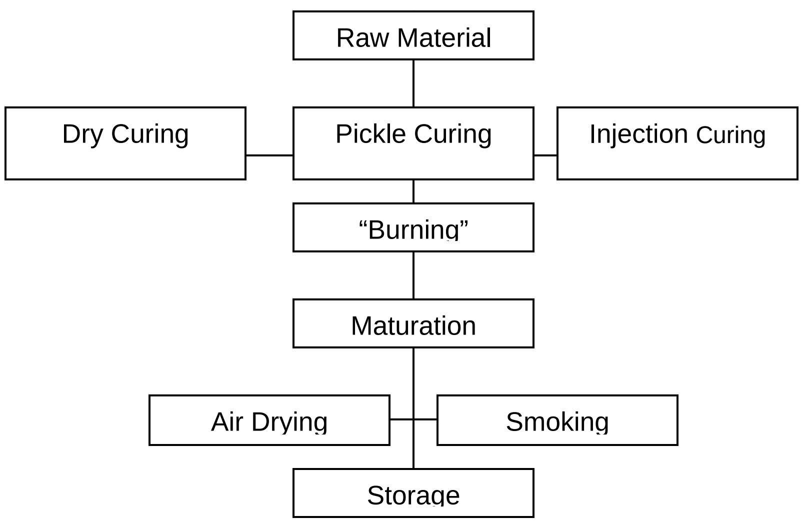
Dried whole muscle products are mostly dry cured. This product category includes the familiar dried hams, such as prosciutto, parma and country ham, but also other dried intact pieces of meat such as dried pork bellies (Pancetta), dried pork shoulders (coppa), and dried beef rounds (bresaola, beef prosciutto, basturma). The primary considerations in producing these products compared to dried sausages are that

- Larger pieces of meat result in slower salt and cure penetration.
- It is preferable to use raw meat materials with pH < 5.8.
- Meat final pH is generally higher.
- Salt extraction at the surface should be minimized.

- Microbial action occurs at the surface only, as the internal tissue is sterile.
- Starter cultures are sometimes added to enhance color, flavor, and preservation, and are mostly non-fermentative.
- The process relies more on osmosis for non-meat ingredients.

An initial process for manufacturing whole muscle products consists of dry mixing the non-meat ingredients with the meat, pickle curing by immersing the meat pieces in concentrated brine, or injection curing by injecting the brine. Injection curing is less common since the water in the brine must be later removed during drying. After the initial salting, the product is held for some period of time at refrigeration temperatures for salt and cure penetration ("burning" period). The product undergoes a maturation period, air drying and smoking (if desired), and storage. The final product is either then sliced and packaged for sale, or sold in the whole piece form for slicing by the final customer.

Whole Muscle Process Flow Diagram



►Dry Curing

The most common salting/curing process for dried whole muscle meats is dry curing; often this class of products is referred to as "dry cured" whole muscle meats. The first step in the dry curing process is mixing the meat pieces with the salt and the other curing mixture. Sometimes spices, sugars and starter cultures are added at this initial step or they can be added later in the re-salting process or immediately prior to the forming. In the very traditional Italian Prosciutto products, no cure (nitrate or nitrite) is added. More modern processes – particularly "American style" products – use nitrate and nitrite. During this initial salting of the product, it is critical to completely cover all the surface area with salt, because the high salt level and the colder temperatures are the only measures protecting against the growth of spoilage and pathogenic microorganisms. Sometimes the salting process for smaller, more uniform, meat pieces is completed with mechanical agitation. For larger hams the salting is done by hand to prevent product tissue damage. For some products the bone is removed prior to salting, while for others it is not. If tumbling is utilized, only a minimal schedule is employed to minimize excessive protein extraction. For most “American style” Prosciutto, the bone is removed and the product is tumbled for the salting process.

During dry curing, moisture migrates from inside the tissue to the surface due to osmotic pressure with the higher salt concentration at the surface. The salt and cure migrate into the tissue due to osmotic pressure. This is a relatively slow process and temperatures must be below 40°F (4.4°C) to minimize microbial growth until the salt percentage is high enough to inhibit many of the spoilage and pathogenic microbes. The salted meat pieces are packed in curing containers that allow draining of the meat juices as the moisture migrates out of the tissues. Some products are shaped or formed at this stage, but generally this shaping takes place after the later salting occurs. During the salting process, the products may be re-salted several times as the added salt migrates into the tissue. Generally, the addition of spices occurs after the last re-salting has been completed.

►Pickle Curing

Although most hams are dry cured as above, some products referred to as “dry cured” do employ a concentrated liquid brine (10-20% salt) in which the meat pieces are immersed for some time to allow for uniform salt distribution in the tissue. This brine can also contain the cure, spices and, possibly, a starter culture, or these ingredients are added after the salting stage. The principles of pickle curing are the same as with dry curing, except that a liquid brine is used. The product cannot be shaped or formed, although this is not necessary at this stage for some products. Products such as pancetta, when brine cured instead of dry cured, are rolled as whole pork bellies after the brining step.

►Injection Curing

Although not common for whole muscle shelf-stable meat products, this process injects the curing ingredients directly into the meat muscle by random injection or artery injection directly into the blood vessels. This artery injection process is most often used on very large bone-in hams. Obviously, the injection curing is a faster, shorter process allowing for rapid salt and cure diffusion throughout the tissue, however the water for the injection medium must be removed during the drying cycle.

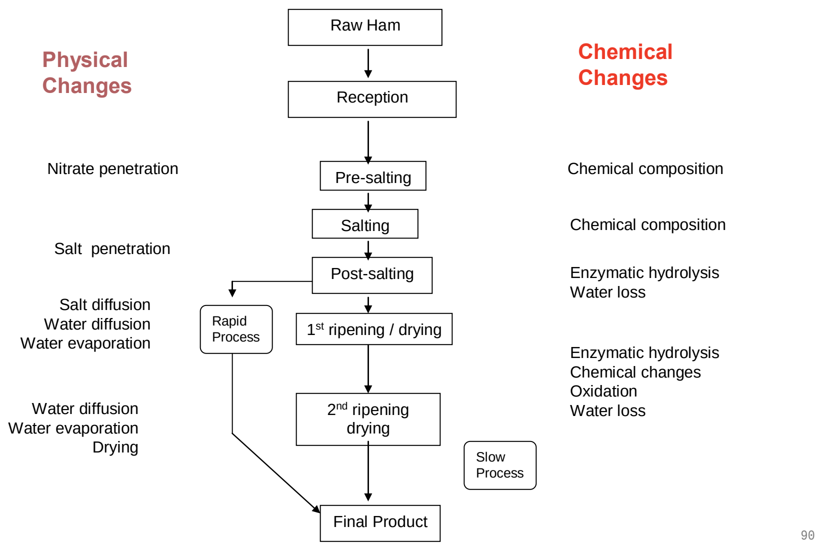
►Burning

After the salting stage, the product enters the "burning" stage. At this stage the product is held at low temperatures (<40°F (4.4°C)) for many days to allow for sufficient salt penetration and equilibration. The goal is to eventually lower the water activity sufficiently to inhibit microorganisms to a point at which the temperature can be elevated. This period often takes many weeks to achieve uniform salt distribution to greater than 4.5% with a water activity below 0.96. Excess surface salt may be removed during this period and only moderate air circulation is desired to avoid surface drying. Some processors may apply a soft fat to the cut surface of the lean tissue to avoid this drying.

►Ripening

At this stage in the process, the whole muscle product should be microbiologically stable due to salt content and lower water activity. The ripeing stage varies widely in terms of temperature, time and optional smoking cycles. During this stage, the products are held at elevated temperatures for drying and flavor development. Long matured hams are held at 59-65°F (15-18.3°C), while short matured hams can be held at 75°F (23.9°C) or higher for shorter periods. During these periods at higher temperatures, the humidity and air circulation is lowered, with further moisture loss. This final step in the process can be from 3 to 12 months in duration.

Changes During Processing: Dry Ham



Dried Whole Muscle Meat Snacks

This product category consists mainly of sliced whole muscle beef jerky and similar whole muscle meat snacks such as beef nuggets, steak tenders, or other such named products that consist of predominantly whole muscle tissue. A variety of other meat snacks such as meat sticks, kippered beef, and assorted chopped and formed or ground and formed products are manufactured similar to sausage-type products. These can be considered a type of dried fermented or non-fermented sausages where manufacturing differences are particle size and final product form (round, flat, etc.).

Most dried meat snacks have a much lower moisture content (22-24%), water activity (<0.80), and moisture protein ration (0.75:1.0 or less) than other products that we have discussed. (Note: The jerky compliance guidelines recommend that a_w be < 0.80; other levels may be acceptable with proper validation.) Typically, the final yield is only about 45-55% from the original marinated or injected product.

Whole muscle beef jerky products are manufactured by pickle curing the meat in either the whole original piece (e.g., beef rounds) or first slicing, and then curing/marinating the individual slices. For that latter case, the raw beef round is first sliced, the slices then tumbled with the brine, cure and spices (optionally marinated slices are held overnight), and placed on screens for subsequent smoking, cooking and drying. This process is used more often with smaller jerky producers. In the new FSIS Compliance Guidelines for Meat and Poultry Jerky, which rely on processing and water activity to ensure safety and shelf stability, several of the options involve heating the marinating solution containing the slices; this would only apply to this type of process where the slices are marinated.

Larger producers of whole muscle beef jerky generally go with the former process whereby whole rounds are injected with a complete brine containing the salt, cure, spices, any preservatives, and often some percentage of ground meat. This injection of ground meat is permitted up to a certain percentage and requires special equipment to inject the ground meat. The ground beef is less expensive and also serves for better bind and more desirable final meat texture (i.e., softer). After injection, the injected rounds (often 35-50% injection) are tumbled and held for a defined period before slicing and placing on screens for smokehouse smoking, cooking and drying.

A typical beef jerky process would consist of first preparing the brine solution with salt, ground beef, seasoning, and cure, followed by injection, tumbling, slicing and smokehouse processing (with 90% relative humidity) as follows:

135°F (57.2°C)	0.5 hour
150°F (65.6°C)	0.5 hour
170°F (76.7°C)	Time to reach a 160°F (71.1°C) internal temperature and water activity of 0.80 (or other validated a_w)

Process Monitoring of Shelf-Stable Dried Meats

Many parameters are monitored in the formulation and processing of shelf-stable, dried meats; most of these are control points for product quality. Only a few are true critical control points for product safety. The following parameters may be monitored.

- Microbiological monitoring; raw materials, in-process, final product
  - Total contamination
  - Relevant meat pathogens
- Moisture content and moisture/protein ratio
- Water activity
- pH
  - Initial of meat mix
  - Rate of change with time
  - Titratable acidity

- Product weight throughout process
- Air circulation velocity and uniformity
- Temperatures
    - Environment
    - Product
- Relative humidity during process

Critical parameters will be discussed in the section on Principles of Preservation of Shelf-Stable Dried Meat Products.

Final Products: Dried Shelf-Stable Meats

Most often, shelf-stable dried meat products rely on a combination of the following characteristics to achieve shelf-stability.

- Low pH/higher acidity
- Low water activity
- Inherent microflora (and starter culture) in non-cooked products

Packaging helps prevent contamination and spoilage due to mold, yeast and undesirable lactic acid bacteria. Pathogens will not grow if recontamination occurs and they may even die off in these products at room temperature. The specific parameters that result in shelf-stability will be discussed further in the section on Principles of Preservation of Shelf-Stable Dried Meat Products.

Production of Freeze-Dried Meat and Poultry Products

Freeze-drying is a method of food preservation that removes almost all of the water from a food product, while leaving the basic physical structure intact. The removal of water prevents the growth of microorganisms, thus preventing the food from spoiling. Depending on how the freeze-dried product is packaged, it can have a shelf-life of 6 months to 20 years.

The process of freeze-drying is different from that of traditional drying which is based on evaporation principles. During evaporation, food products are heated to force the water out of the product by converting it from a liquid to a vapor. The level of heat needed to accomplish this also changes the shape, texture and composition of the food. During the freeze-drying process, water is removed from the food while it is frozen by a process known as sublimation. The low-heat required for sublimation helps to preserve the quality, flavors and texture of the freeze-dried products.

The physics behind freeze-drying is that of sublimation – a phase shift from solid water (ice) directly to gaseous water (vapor). Water exists in one of three phases (solid (ice), liquid (water), or gaseous (vapor or steam)) depending on the temperature and atmospheric pressure. At sea level water will turn from a liquid to a solid at 32°F and from a liquid to a gas at 212°F.

Equipment that will deep freeze and pull a vacuum is needed for freeze-drying. An all-inclusive freeze-drying chamber will incorporate heating units (generally heated shelves), a freezing coil and a vacuum pump. After the unfrozen product is put into the chamber, the temperature in the chamber is dropped to freeze the product. The product is frozen solid (-20°F or lower) to a level where the water is separated from other compounds (on a cellular level) and forms ice crystals. Following the freezing step, a vacuum is pulled on the chamber, forcing out the air and lowering the pressure to about 0.06 atmospheres (ATM). (Sea level is 1.0 ATM.) Lowering the pressure alone will not achieve the conversion from solid water to vapor – a small amount of heat is also needed. As the ice crystals in the product turn directly into vapor, the vapor (and resulting moisture) is pumped out of the vacuum chamber to the freezer compressor. This completes the separation of the water from the food product and results in product drying. The drying process can take several hours to days to complete because a gradual drying is desired to maintain the structure of the product. After the product is completely dry (removing about 98% of the water) the product is packaged.

The packaging materials for freeze-dried products play a key role in maintaining the shelf-stability of the product. Although completely dried, these products are still subject to oxidation degradation of the fat components. The packaging materials used – typically a flexible pouch or a metal can are used to provide a moisture free package. Often an oxygen absorbing “scavenger” is packaged with the product or a nitrogen flush of the package prior to sealing is utilized to help extend the shelf life by eliminating oxygen from the product.

Product preparation procedures prior to freeze-drying will depend on the product. Cooked meat and poultry pieces may be freeze-dried to serve as ingredients in other consumer products such as dried soup mixes. Some processors of freeze-dried entrees (e.g., chicken ala king or spaghetti with meat sauce) will prepare the product with similar methods used for the production of frozen entrees. The completed entrée is then freeze-dried.

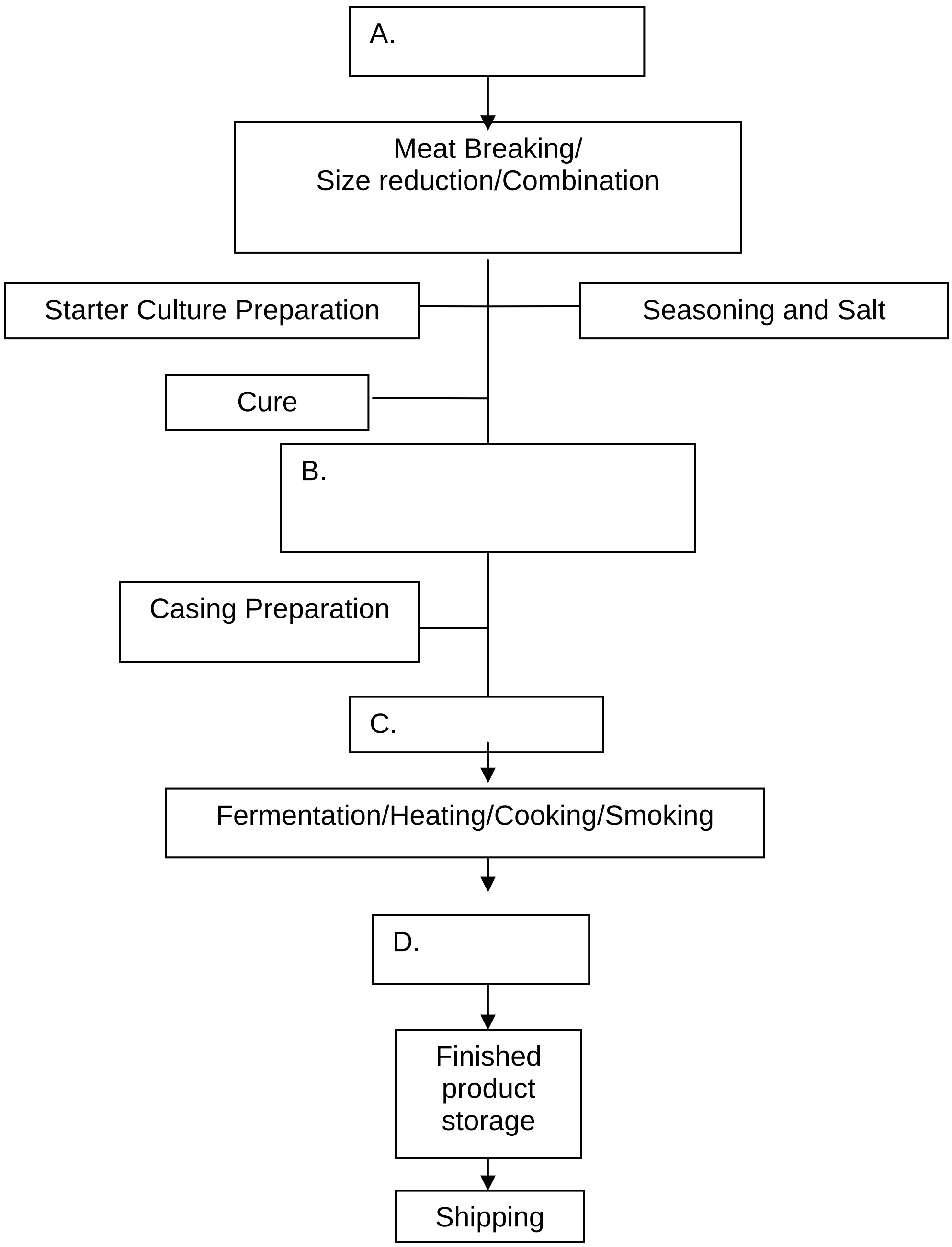
Workshop: Process Familiarization for Dried Meats

Review the following flow diagrams for two different dried meat products that we have discussed. Several process steps have been omitted from the flow diagram. Using the list of process steps provided, fill-in the omitted steps. In addition, please answer the questions pertaining to the flow diagrams.

Note: These flow diagrams are simplified for educational purposes.

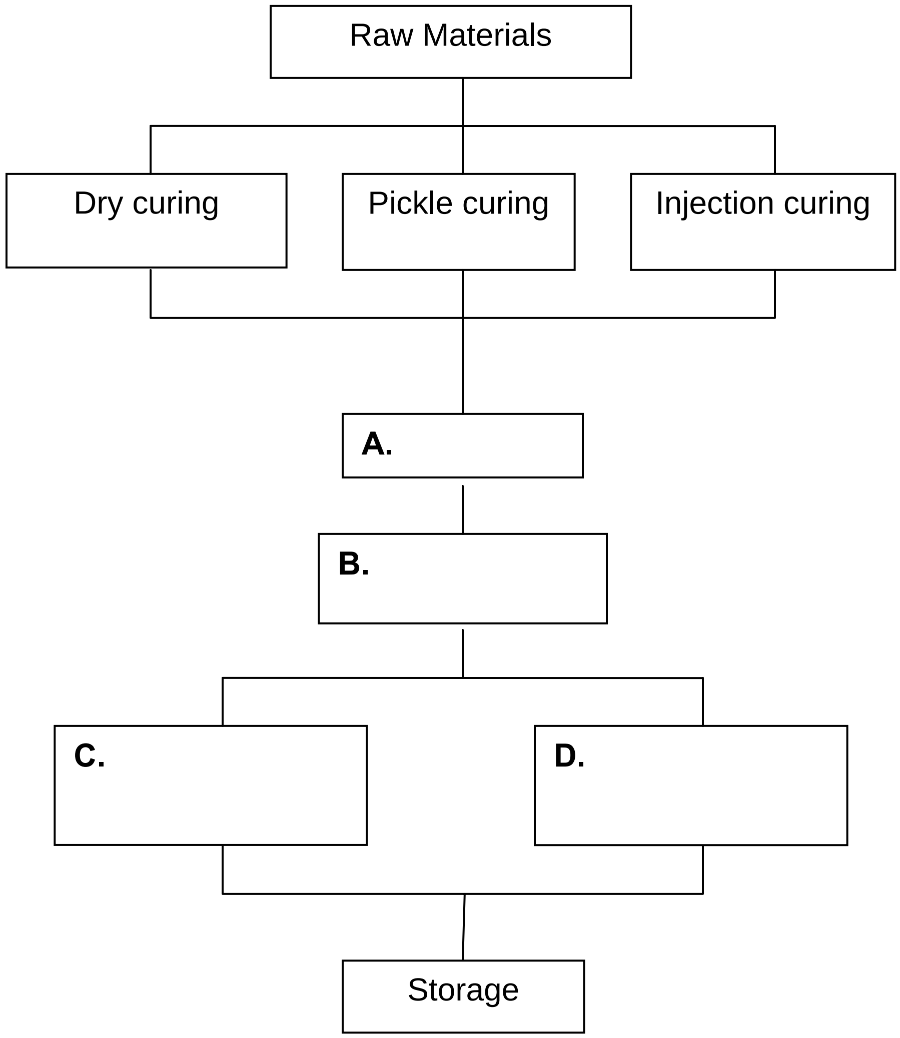
Fermented Dry Sausage

Select from Drying, Formulation: Mixer or Cutter, Meat Tempering, and Stuffing to fill in the flow chart.



Whole Muscle Process

Select from Air drying, Burning, Maturation, and Smoking



Questions:

1. Why is the product fermentation process completed prior to the heating and or drying step?

2. Are fermented dry sausages formulated cold? Why or why not?

3. Would a processor of dried whole muscle product such as a country ham conduct dry curing, pickle curing and injection curing for the same product? Which method is most commonly used for country ham products?

What is the purpose of the burning step for dried whole muscle products?